INFLUENCE OF ACETOGENIC VERSUS PROPIOGENIC SUPPLEMENTS ON ADIPOSE TISSUE ACCRETION IN STOCKER STEERS GRAZING RYEGRASS PASTURE

A Thesis

by

EMALEE KATE BUMPUS

Submitted to the Office of Graduate Studies of
Texas A&M University
in partial fulfillment of the requirements for the degree of

MASTER OF SCIENCE

May 2006

Major Subject: Animal Science

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Approved by:

Chair of Committee,	Jason E. Sawyer
Committee Members,	Thomas D. A. Forbes
	Andy D. Herring
	J. William Holloway
Head of Department,	Gary Acuff

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ABSTRACT

Influence of Acetogenic versus Propiogenic Supplements on Adipose Tissue Accretion in Stocker Steers Grazing Ryegrass Pastures. (May 2006)

Emalee Kate Bumpus, B.S., University of Tennessee at Martin

Chair of Advisory Committee: Dr. Jason E. Sawyer

Fifty-eight high grade Bonsmara steers were used to evaluate effects of high-fiber versus high-starch pasture supplements on subcutaneous (s.c.) and intramuscular (i.m.) adipose tissue accretion during growing and finishing phases. Cattle were stratified by body weight (BW), randomly assigned to one of three treatments, and placed on irrigated ryegrass pastures. Treatments were 1) no supplement (NC); 2) commercially available, pelleted high roughage (HR) supplement, designed to promote higher acetate fermentation, fed at 1.36 kg/hd (as-fed) 6 d/wk; or 3) corn-based high starch (HS) supplement, designed to promote higher propionate fermentation, fed at the same rate and frequency as HR. Throughout growing (140 d) and finishing (119 d) phases, full BW was measured every 28 d. Ultrasound ribeye area (REA), percent i.m. fat (IMF), and 12th rib fat thickness (BF) were measured on d -15, 56, 112, 182, and 231. Mixed model repeated measures analysis was performed on growth performance and ultrasound data. All responses increased over time ($P < 0.01$). Treatment by time interaction ($P = 0.05$) for BW was due to treatment rank changes among days; within day separations were minimal. Neither treatment nor interaction affected ($P > 0.20$) IMF, but treatment influenced ultrasound REA ($P = 0.05$); HS-fed steers had larger REA than

HR-fed steers; NC steers were intermediate. Treatment effects on REA with similar IMF suggest that HS-fed steers accreted a greater total amount of i.m. fat. One-way structure analysis of carcass data was performed. Treatment did not affect hot carcass weight (HCW), carcass REA, or carcass fat thickness (FAT) ($P > 0.48$), but tended ($P = 0.15$) to affect marbling score (MARB). Supplemented cattle tended to have greater MARB than non-supplemented steers, and MARB was greater for HS-fed steers than that of HR-fed steers. The relationship between carcass REA and MARB is consistent with the relationship observed between ultrasound REA and IMF. These observations suggest that source of energy supplementation partitioned nutrients during the growing phase to favor i.m. fat accretion.

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INTRODUCTION

Intramuscular (i.m.) fat content (marbling) is a primary component of the USDA quality grading system, and therefore is a determinant of carcass price, with greater i.m. fat deposition being associated with an increase in price. Subcutaneous (s.c.) fat thickness is a component of the USDA yield grade equation, and typically, increases in s.c. fat result in diminished carcass price. Current finishing methods involve feeding cattle for longer periods of time or to a predetermined backfat thickness in an attempt to increase marbling and carcass weight. These methods may be risky, as the potential for yield grade discounts is increased. Strategies which enhance quality grade without negatively impacting yield grade are desirable, as they may increase carcass value with minimum risk of incurring discounts. Cattle in the finishing phase are often managed in a uniform manner, increasing the logistical difficulty of alternative management strategies. Therefore, growing programs which result in a predisposition toward carcass enhancement may optimize responses.

It is well documented that s.c. and i.m. adipose tissues are metabolically distinct and differ in rates of development as well as substrates used for synthesis (Hood and Allen, 1978; Smith and Crouse, 1984). These metabolic differences may allow for the specific manipulation of individual fat depots. Acetate is the preferred substrate for s.c. adipose tissue accretion, while glucose carbon is utilized preferentially for i.m. fat accretion (Smith and Crouse, 1984). Hypothetically, an increase in available glucose

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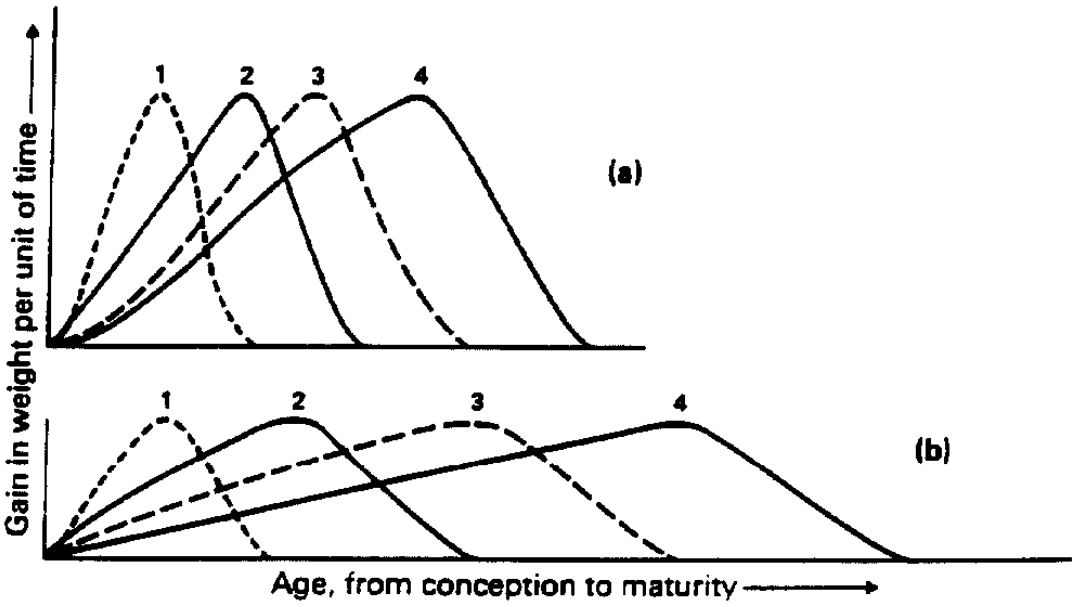
carbon might result in an increase in lipogenesis in i.m. adipose tissue relative to s.c. adipose tissue.

Forage-based growing phases are commonly used by beef cattle producers and may reduce overall production costs; however, additional value may be added to the calves by manipulating s.c. and/or i.m. fat characteristics and by sorting and managing groups of animals based on marbling potential. Today's beef market provides an array of end points for products of different specifications. The ability to predict or manipulate product characteristics during the growing phase will benefit producers by allowing them to optimize available forages and production practices to produce a consistent and desirable product that meets market demands.

REVIEW OF LITERATURE

Body and Carcass Composition

According to Gerrard and Grant (2003), growth is the general expansion of size caused by the accretion of tissues similar in composition to that of the original tissue, while development is defined as the gradual progression from a state of lower complexity to a state of higher complexity. Growth of all animals follows a sigmoidal curve (accumulative) when time and growth units (typically weight) are used as variables, however the shape of the curve will vary due to factors that include, but are not limited to, species, breed, and sex (Gerrard and Grant, 2003). Tissues grow and develop based on importance or priority for survival; nervous tissue develops earlier than bone tissue. Bone tissue is followed by muscle and then fat. Within each tissue, growth and development of certain depots take priority over others (Figure1; Owens et al., 1993; Gerrard and Grant, 2003). It is generally accepted that deposition of fat in individual depots occurs in some order (i.e., visceral, intermuscular, subcutaneous, intramuscular) (Andrews, 1958; Gerrard and Grant, 2003) and that order and rate of deposition is dependant on many variables. Likewise, many factors affect carcass composition, including age, sex, breed or genetic makeup, previous and current planes of nutrition, and body weight. Carcass composition is of major importance to the beef industry; therefore, identification of factors or strategies that influence development of tissues is important to improve beef products.



1	2	3	4
Head	Neck	Thorax	Loin
Brain	Bone	Muscle	Fat
Metatarsus	Tibia-fibula	Femur	Pelvis
Kidney fat	Intermuscular fat	Subcutaneous fat	Intramuscular fat

Figure 1. Growth rates of various tissues and various sites in animals fed for a) rapid or b) slow rates of growth. (Owens et al. 1993).

All tissues of the body do not grow and develop at the same rate (Gerrard and Grant, 2003); therefore, changes in body or carcass composition should be thought of in a relative manner. One way to think about changes in composition is to consider how they relate to the growth unit (body weight or carcass weight) rather than time. Bruns et al. (2004) allotted steers to five slaughter groups to achieve hot carcass weights (HCW) of 204, 250, 295, 340, and 386 kg (Slaughter group 1, 2, 3, 4, and 5, respectively). Longissimus muscle area, marbling score, and 12th rib intramuscular fat content increased ($P < 0.0001$) in a linear fashion with increasing HCW. Similarly, May et al. (1992) reported a linear increase in longissimus muscle area concurrent with increasing HCW, but found a quadratic increase ($P < 0.05$) in marbling score. Bruns et al. (2004) also reported composition of gain and fractional growth rates. The percentage of carcass fat increased ($P < 0.05$) in a quadratic fashion as HCW increased, whereas the percentage of carcass protein and moisture decreased quadratically ($P < 0.05$) with increased HCW. Fractional growth, expressed as percent per day, of protein, fat, and 12th rib intramuscular fat decreased with increasing HCW. This is attributed to the animal approaching mature size, when rate of tissue development slows, however the proportions of tissue continue to change (Bruns et al. 2004).

Adipose Tissue Growth and Development

General Description of Adipose Tissue. Adipose tissue is a complex tissue consisting primarily of adipocytes, but also containing blood vessels, nerves, fibroblasts, and other cell types (Gurr et al., 2002; Mersmann and Smith, 2004), and functions as an energy reserve, an endocrine organ, to provide insulation, for protection of internal

organs, to generate heat, and is related to eating qualities of beef (Gerrard and Grant, 2003; Mersmann and Smith, 2004). There are two types of adipose tissue: brown, which is present in most newborn mammals and recedes within the first few days or weeks of life, and white, which is typically thought of as fat and increases as the animal grows. There are several adipose tissue depots in beef cattle, differing in order and rates of development; however, there is debate as to the order of accretion in different depots. Gerrard and Grant (2003) state that the visceral depot is the first to develop, followed by subcutaneous, intermuscular, and intramuscular depots, respectively, while Andrews (1958) reported the order to be visceral, intermuscular, subcutaneous, and intramuscular. Conversely, Bruns et al. (2004) imply that intramuscular adipose tissue is not a late-maturing tissue, but one that has the potential to develop earlier in growth if nutritional needs are met and one that develops at a consistent rate relative to growth of other carcass tissues.

Adipogenesis. Smith et al. (2000), Gerrard and Grant (2003), and Mersmann and Smith (2004) describe the process of adipogenesis. Adipogenesis occurs when mesenchymal cells derived from the embryonic mesoderm give rise to adipoblasts. Adipoblasts will collect and replicate within the stroma; when replication ceases, differentiation may occur to form a preadipocyte. Small lipid droplets will begin to appear inside the preadipocyte, forming a developing or immature adipocyte, until the lipid droplets coalesce to form a single large globule. The presence of a single large globule is characteristic of a mature adipocyte.

Hyperplasia and Hypertrophy of Adipocytes. Gerrard and Grant (2003) and Mersmann and Smith (2004) state that an increase in adipose tissue mass in a growing animal is the result of some combination of hyperplasia (increase in cell number) and hypertrophy (increase in adipocyte size). Increases in adipose tissue mass due to hyperplasia or hypertrophy vary with respect to depot and age, among other known and unknown factors. Differentiated adipocytes are not capable of hyperplasia (Mersmann and Smith, 2004), thus an increase in adipose cell number is the result of preadipocyte division. It is also important to note that when adipocytes reach maximal size, an unknown trigger causes hyperplasia to increase (Mersmann and Smith, 2004).

The majority of adipose cell hyperplasia occurs prenatally (Gerrard and Grant, 2003; Mersmann and Smith, 2004); however, hyperplasia is observed in growing animals and, in instances of excessive energy intake, mature animals exhibit hyperplasia as well. When comparing the perirenal adipose depot of 8-month-old Hereford steers and 14-month-old Hereford X Angus steers, Hood and Allen (1973) reported an increase in the number of adipose cells per perirenal depot (3.15×10^9 to 7.44×10^9, $P < 0.05$; 8- and 14-month-old steers, respectively), indicating cell hyperplasia in the young animal was occurring. Cianzio et al. (1985) also reported apparent cell hyperplasia in the intramuscular depot of 11- to 19-month-old crossbred steers with the total number of intramuscular adipocytes increasing ($P < 0.05$) from 4.8×10^9 to 8.0×10^9.

The number of preadipocytes decreases with age, but may vary among depots and, as previously stated, when the animal consumes excessive amounts of energy (Mersmann and Smith, 2004). The absence of small adipose cells (< 70 μm) in the

perirenal and subcutaneous depots of the 14-month-old Hereford X Angus steers and the 14-month-old Holstein steers suggested that hyperplasia in these depots was complete before 14 months of age (Hood and Allen, 1973). Furthermore, Cianzio et al. (1985) quantified the number of adipocytes in 5 different fat depots (subcutaneous, intermuscular, brisket, kidney, and mesenteric) in steers aged 11 to 19 months, and the total number of adipocytes remained relatively constant (55×10^9 adipocytes), also indicating hyperplasia may have ceased in these depots, but not in the intramuscular depot.

Most of the increase in adipose tissue mass in growing animals is due to hypertrophy of adipocytes (Cianzio et al., 1985; Mersmann and Smith, 2004). Hypertrophy occurs when a cell increases in diameter and volume due to the accretion of triacylglycerol within the adipocyte (Gerrard and Grant, 2003; Mersmann and Smith, 2004). Cianzio et al. (1985) reported an increase in average adipocyte diameter in six different fat depots as steers grew from 11 months of age to 17 months of age. In close agreement is the study by Hood and Allen (1973) where average cell diameter (75.0 vs. 55.5 μm) and volume (25.8 vs. 10.4 μm^3, 10^4) in the perirenal depot was greater ($P < 0.05$) in 14-month-old Hereford steers compared to 8-month-old Hereford steers (carcass weight 168 kg and 113 kg, 14- and 8- month-old respectively).

Subcutaneous vs. Intramuscular Adipose Tissue. Subcutaneous and intramuscular adipose tissue depots are metabolically distinct, differing in rates of accretion and substrates preferentially used for synthesis, as well as in some physical characteristics of adipocytes within each depot. Moody and Cassens (1968) and Smith

and Crouse (1984) reported that the mean diameter of longissimus dorsi intramuscular adipose cells was smaller than that of subcutaneous adipocytes. Likewise, Hood and Allen (1973) reported smaller cell diameters of bovine intramuscular adipose cells when compared to adipose cells in the subcutaneous depot from the same animals. This could be due to a greater number of preadipocytes in the intramuscular depot than in subcutaneous depot (Cianzio et al., 1985), fragmentation during freezing (Smith and Crouse, 1984), physical constraints of the depot, or differentiation in rate of lipid filling.

Metabolic differences in subcutaneous and intramuscular fat have been well documented. Fatty acid synthesis in intramuscular adipose tissue occurs at a lower rate than in subcutaneous adipose tissue (Chakrabarty and Romans, 1972; Hood and Allen, 1978; Smith and Crouse, 1984). Furthermore, differences in lipogenic precursors used preferentially in each depot have been reported. Hood and Allen (1978) found that the rate of incorporation of acetate into total fatty acids was higher in the subcutaneous adipose depot than the intramuscular depot. Smith and Crouse (1984) stated that acetate provided a greater percentage of acetyl units for fatty acid synthesis in the subcutaneous depot than the intramuscular depot (67-79% vs. 10-26%, respectively). Also reported by Smith and Crouse (1984) was the percentage of acetyl units provided by glucose for fatty acid synthesis in each depot (1-10% vs 51-76%, subcutaneous and intramuscular, respectively). Therefore, it is clear that acetate is the preferred substrate for the subcutaneous depot, and glucose is preferred by intramuscular adipose tissue. Due to these differences, increasing available glucose or glucose precursors such as propionate, may potentially allow for increased intramuscular adipose accretion.

Nutritional and Managerial Effects on Adipose Tissue Accretion. There are several nutritional and managerial practices that influence deposition of fat. Typically, cattle fed primarily grain will have greater amounts of fat than cattle fed primarily forage/roughage. Brangus crossbred steers finished on a high grain diet had greater marbling scores and quality grades ($P < 0.01$) and fat thickness ($P < 0.05$) than steers finished on an all-forage diet (Williams et al., 1983). In another study, Angus X Simmental steers were allotted to one of three treatments: 1) ad libitum access to a 50% grain diet (ALC); 2) limit-fed a 70% grain diet (LFC); or 3) ad libitum access to a 60% haylage diet (119 to192 d of age) and 25% haylage diet (193 to 259 d of age) (ALF). Fat thickness measured via ultrasound at 260 and 316 d of age was greater ($P < 0.01$) for the ALC group (0.79 cm and 1.02 cm, respectively) as compared to the LFC group (0.48 cm and 0.86 cm) and the ALF group (0.53 cm and 0.84 cm) (Schoonmaker et al., 2004).

Time-on-feed also impacts fat accretion. Miller et al. (1987) studied the effect of time-on-feed on carcass traits of steers slaughtered at the same age and reported concomitant increases ($P < 0.01$) in adjusted fat thickness, marbling score, and USDA quality grades as time-on-feed increased. May et al. (1992) serially slaughtered Angus X Hereford steers every 28 d, in part to determine the effect of days fed on beef palatability, and reported a linear increase ($P < 0.01$) in fat thickness over the 196 d finishing period, as well as a quadratic increase ($P < 0.05$) in marbling score up to 112 d of finishing.

Use of Ultrasound Technology to Measure Body Composition

There is a growing demand to predict carcass attributes in live animals, and there are benefits to obtaining this knowledge: determining superior genetic lines for carcass traits or the ability to manage cattle for a specific carcass attribute (i.e., quality grade, red meat yield for example). The use of ultrasound technology provides a way to estimate body composition, predict carcass traits, and to track compositional changes over time in the live animal. However, operators and producers may question the reliability of these predictors.

Several studies have demonstrated the repeatability (Brethour, 1992; Herring et al., 1994; Hassen et al., 1999) and accuracy (Brethour, 1992; Herring et al., 1994; Greiner et al., 2003) of ultrasound technology in the live animal to predict carcass longissimus muscle area, backfat thickness, rump fat thickness, and percentage of intramuscular fat.

Brethour (1992) utilized five diverse groups of cattle (including yearling heifers and steers, heavy steers, 2- and 3-yr-old heifers, and 6-yr-old cows; n = 217) to determine the repeatability of ultrasound measures of subcutaneous fat thickness between the 12^{th} and 13^{th} rib. Cattle were scanned twice, usually on consecutive days, and previous measurements were concealed. The correlation between the two consecutive ultrasound measurements was 0.975 (Brethour, 1992). In a study by Herring et al. (1994), repeatability of ultrasound backfat and longissimus muscle area measurements was evaluated using 44 Hereford-sired steers. Steers were scanned on two consecutive days by three different technicians using two different machines.

Repeatability of backfat measures ranged from 0.69 to 0.90 with technician 1 being the most repeatable (0.90 and 0.86, machines 1 and 2, respectively); repeatability of longissimus muscle area ranged from 0.36 to 0.90, with technician 1 again being the most repeatable (0.82 and 0.90, machines 1 and 2, respectively) (Herring et al., 1994). Bulls, heifers, and steers (n = 144) were scanned to estimate percentage of intramuscular fat. Five to six images were obtained for each animal to determine repeatability. Overall repeatability was 0.63, and ranged, depending on sex, from 0.52 to 0.73 with steers being the most repeatable ($P < 0.05$) (Hassen et al., 1999).

Five hundred eighty cattle, described by the authors as diverse, were used to determine the relationship between ultrasound backfat measurements and carcass backfat measurements. Carcass measurements averaged 8% higher ($P < 0.001$) than ultrasound measurements, and the correlation between the two measures was 0.90 in Exp.1 (n = 580) and 0.92 in Exp.2 (n = 175) (Brethour, 1992). Ultrasound and carcass backfat and longissimus muscle area measurements were taken on 544 steers over a 2-yr study (yr 1, n = 282; yr 2, n = 252) to determine the relationship between the two methods of measurement (Greiner et al., 2003). Ultrasound measurements were taken within five days of slaughter for each individual animal. Correlations for backfat were 0.86 and 0.90 (yr 1 and yr 2, respectively) and 0.89 when years were combined. Longissimus muscle area correlations between ultrasound and carcass measurements were 0.91, 0.79, and 0.86 (yr 1, yr 2, and combined, respectively).

The relationship between ultrasound and carcass measurements of intramuscular fat content has been studied as well (Brethour, 2000a). Calves (n = 144; 130 steers, 14

heifers) were scanned to estimate marbling a few days after weaning. Cattle were slaughtered in three groups according to BW and ultrasound backfat measurements and carcass marbling scores were obtained. The correlation between post-weaning ultrasound estimates of marbling score and carcass marbling score was 0.32 (Brethour, 2000a).

In many studies evaluating the relationship between ultrasound and carcass measures, ultrasound measurements were obtained just prior to slaughter. However, many times ultrasound measurements are taken at weaning and sometimes throughout the animal's life. How accurate are ultrasound measurements taken at times other than just prior to harvest? To address this question, Crews et al. (2002) obtained longissimus muscle area and fat thickness ultrasound measurements on steers (n = 116), bulls (n = 224), and heifers (n = 257) approximately 60-d after weaning, as yearlings, and just prior to harvest. Subsequent carcass measures were recorded for each individual. Residual correlations (adjusted for year of birth, gender, and age at measurement) for weaning, yearling, and prior-to-harvest ultrasound measurements of longissimus muscle area were high and ranged from 0.79 to 0.86; fat thickness residual correlations were also moderate to high, ranging from 0.64 to 0.86 (Crews et al., 2002). Crossbred steers (n = 406) were serially scanned by Wall et al. (2004) using ultrasound technology for longissimus muscle area, backfat thickness, rump fat depth, and percentage of intramuscular fat. Cattle were scanned at regular intervals to determine if ultrasound measurements can be used to predict carcass composition before slaughter. Correlation coefficients for ultrasound and carcass longissimus muscle area measures were 0.52 (100 d pre-

slaughter) and 0.66 (7 d pre-slaughter). The relationship between ultrasound backfat measures taken 100 d before slaughter or within 7 d of slaughter and carcass backfat measures were 0.58 and 0.74, respectively. Correlations between percentage of intramuscular fat and carcass marbling score were 0.63 and 0.61 (100 d before slaughter and 1 wk before, respectively) (Wall et al., 2004).

The accuracy and repeatability (precision) of ultrasound technology to predict carcass traits and track changes in body composition appears to be dependent on several factors including, but not limited to, trait measured and technician. In the literature reviewed for this thesis, correlation coefficients for repeatability ranged from 0.69 to 0.975 for backfat thickness, 0.36 to 0.90 for longissimus muscle area, and 0.52 to 0.73 for percentage of intramuscular fat. Variation in backfat and muscle correlations could be attributed to differences in technician ability (Herring et al., 1994). Variation in correlations for percentage i.m. fat were dependent on gender of the animal within a technician (Hassen et al., 1999), and presumably technician effects observed for other carcass traits could influence precision of i.m. fat measurement. Accuracy of ultrasound measurements related to carcass measurements ranged from 0.58 to 0.90 for backfat, 0.52 to 0.91 for longissimus muscle area, and 0.32 to 0.76 for i.m. fat or marbling score. These correlation values are from a variety of studies, in which technician, equipment, age, sex, weight, and genetic makeup of cattle, and time of scan were all different and may contribute to this range in correlations. According to Ribeiro (2005) technician (field and lab) experience is the most important factor for achieving accurate results.

Performance of Stocker Cattle

Forage-based growing phases (stocker programs) are commonly used by beef cattle producers to promote relatively inexpensive weight gain in calves by utilizing available forages. Many factors may affect performance, including age, weight, sex, or genetic makeup of the calf, and quality and quantity of the forage.

Cattle Performance on Rye and Ryegrass Pastures. Simmental crossbred calves (n = 40) allotted to rye-ryegrass pastures with access to free-choice mineral gained 0.99 kg/d in Trial 1 and calves in Trial 2 (n = 30) gained 1.07 kg/d (Grigsby et al., 1991). Average daily gains of 1.33 kg were reported for steers grazing rye-ryegrass pastures during the first 90 of the grazing season (Lippke and Forbes, 1993). Yearling steers (n = 90) grazing ryegrass pastures 70 to 91 d gained an average of 0.70 kg/d (Lippke and Holloway, 1995). Wyatt (2002) reported performance of Angus and Brangus steers grazing two varieties of ryegrass. Steers also had access to round bales of good quality hay that were provided to extend the grazing season as long as possible. Average daily gains presented are based on average gain over the three seasons. Steers grazing Jackson ryegrass gained 1.11 kg/d and steers grazing Marshall ryegrass gained 1.13 kg/d. Gains for cattle grazing rye and ryegrass pastures averaged 0.72 kg/d over a three year study by Aiken et al. (2004).

Cattle Performance on Other Small-Grain Forages. Calves grazing winter wheat pasture (stocking rate, 0.4 to 1.0 ha/calf depending on year of study) averaged gains of 0.63 kg/d (Phillips et al., 2001). Average gains of 1.03 kg/d were reported for steers grazing irrigated winter wheat pasture by Choat et al. (2003). Average daily gains

for two groups of steers grazing winter wheat at different stocking densities (1.1 steers/ha for high-gaining group; 2.45 steers/ha for low-gaining group), as reported by Hersom et al. (2004), were 1.31 and 1.10 kg/d for the high-gaining group during years 1 and 2, respectively. Gains for the low-gaining group were 0.54 and 0.68 kg/d during years 1 and 2, respectively.

On average, across various stocking densities, stocker cattle consuming ryegrass pasture gain 1.01 kg/d with reported values ranging from 0.70 to 1.33 kg/d. These values are comparable to those of cattle grazing small grains pastures such as winter wheat (μ = 0.88 kg/d; range 0.54 to 1.31 kg/d).

Supplementation of Stocker Cattle

Crossbred calves grazing rye-ryegrass pastures and consuming a monensin-containing corn supplement (average daily consumption, 0.75 kg/d and 0.51 kg/d, trial 1 and 2, respectively) gained 57% and 16.9% more (1.55 kg/d and 1.24 kg/d, trial 1 and 2, respectively) compared to non-supplemented calves (0.99 kg/d and 1.07 kg/d, trial 1 and 2, respectively) (Grigsby et al., 1991). A three-year study was conducted by Horn et al. (1995) to evaluate effects of two types of monensin-containing energy supplements on performance of fall-weaned steer calves (n = 468, yr 1, 2, and 3 pooled) grazing winter wheat. Supplementation increased ($P < 0.001$) ADG by 0.15 kg/d (1.07 kg/d vs. 0.92 kg/d, supplemented vs. non-supplemented, respectively); however, type of supplement had no effect ($P > 0.30$) on gain (Horn et al., 1995). Commercial stocker steers that were implanted and fed 0.90 kg/hd daily of a monensin-containing corn supplement gained an average of 1.16 kg/d grazing ryegrass pastures and 1.34 kg/d grazing rye-

ryegrass pastures; there was no negative control group in this study (Hubbell et al., 2000). Gains of 1.10 kg/d, 1.07 kg/d, and 0.83 kg/d (years 1, 2, and 3, respectively) were reported for calves grazing bermudagrass/dallisgrass pastures overseeded with annual ryegrass and consuming 0.90 kg/hd daily of a monensin-containing grain sorghum-based supplement and for calves receiving the same supplement (no negative control) while grazing bermudagrass/dallisgrass pastures overseeded with wheat and ryegrass (1.03 kg/d, 0.92 kg/d, and 0.85 kg/d (years1, 2, and 3, respectively) in a study conducted by Coffey et al. (2002). Gains of supplemented cattle ranged from 0.83 to 1.55 kg/d over a variety of conditions, however two studies compared supplemented cattle to non-supplemented cattle and reported 16.3 to 57 % increase in gain due to supplementation. Supplement efficiency, expressed as amount consumed:gain was 1.34 and 3 (trial 1 and 2, respectively; Grigsby et al., 1991).

Feedlot Performance and Carcass Characteristics of Stocker Cattle

Feedlot Performance. Many studies evaluating feedlot performance of cattle following different growing programs have been documented. Horn et al. (1995) conducted experiments to evaluate effects of supplementation and stocking density on performance of steer calves grazing winter wheat and subsequent feedlot performance. In yr 2 of the 3-yr study (yr 1 did not report feedlot performance), non-supplemented cattle were lighter ($P < 0.001$) at feedlot entry, heavier ($P < 0.09$) at the conclusion of finishing, and had greater ($P < 0.05$) feedlot ADG than supplemented cattle (1.72 kg vs 1.63 kg, respectively). However, in yr 3, there was no difference ($P > 0.55$) in final BW of non-supplemented and supplemented cattle and no difference ($P > 0.80$) was reported

for feedlot gain due to supplementation (1.52 kg vs. 1.51 kg, non-supplemented and supplemented, respectively) (Horn et al, 1995). In a study by Wertz et al. (2001) early-weaned heifers grazed fescue for 18 mo (referred to as yearlings) or were fed one of two concentrate diets (25% concentrate, ad libitum vs. 90% concentrate, limit-fed; referred to as calves) for 119 d before being placed in the feedlot to determine effects of post-weaning nutritional management on feedlot performance. Yearling heifers were older (588 d of age; $P < 0.01$) and heavier (374.6 kg; $P < 0.01$) at feedlot entry than heifer calves fed 90% concentrate (216 d of age; 176.9 kg). Average daily gain tended ($P < 0.10$) to be greater for yearlings than for 90% concentrate calves (1.48 kg and 1.37 kg, respectively), but calves gained more efficiently ($P < 0.01$) than yearlings (Wertz et al., 2001). Feedlot initial and final BW were greater ($P < 0.001$) for steers previously grazing winter wheat than those grazing native range, however ADG in the feedlot was greater ($P < 0.02$) for native range steers than winter wheat steers (Choat et al., 2003). In a two-year study, fall-weaned steers were randomly assigned to graze winter wheat at one of two stocking densities (1.1 steers/ha and 2.45 steers/ha) or to graze dormant native range to evaluate effects on feedlot performance. Feedlot ADG did not differ (yr 1, $P = 0.43$; yr 2, $P = 0.24$) among treatments and live gain efficiency was not different ($P = 0.41$ and $P = 0.58$, yr 1 and 2, respectively) (Hersom et al., 2004). Angus-Hereford steer calves weaned in May were allotted to one of three treatments: 1) steers entered feedlot at weaning (calf-fed), 2) steers grazed irrigated pasture for 4 mo before entering feedlot (short yearlings), and 3) steers grazed irrigated pasture and range for 12 mo before entering feedlot (long yearlings). Feedlot ADG did not differ ($P > 0.10$) among

treatments, but tended to increase with longer backgrounding periods. Additionally, days on feed decreased ($P < 0.10$) with increased backgrounding time (Sainz and Vernazza Paganini, 2004).

Carcass Characteristics. Effects of post-weaning nutritional management on carcass traits have also been documented. No differences in HCW ($P > 0.12$) or marbling score ($P > 0.95$) were seen among steers that had supplemented with one of two energy supplements while grazing winter wheat during the growing phase versus non-supplemented steers grazing winter wheat (Horn et al., 1995). Early-weaned Angus X Simmental heifers grazed fescue for 18 mo (referred to as yearlings) or were fed one of two concentrate diets (25% concentrate, ad libitum vs. 90% concentrate, limit-fed; referred to as calves) for 119 d before being placed in the feedlot and were fed until visual appraisal of 1.5 cm fat thickness. Calves fed 90% concentrate had lighter ($P < 0.01$) HCW than yearlings; however, yearling HCW exceeded acceptable industry standards (329.4 kg vs. 435.3 kg, calf vs. yearling, respectively). When expressed as square cm per 100 kg of carcass weight, 90% concentrate heifers had larger ($P < 0.01$) longissimus muscle area than yearlings. No differences in marbling ($P = 0.48$) or quality grade ($P = 0.98$) were seen among calves and yearlings (Wertz et al., 2001). Carcass characteristics reported for steers grown on winter wheat pasture or native range pasture revealed greater HCW ($P < 0.001$) and marbling score ($P < 0.001$) for wheat steers than native range steers; however, 12th-rib fat ($P = 0.64$) and quality grade ($P = 0.23$) did not differ among treatments (Choat et al., 2003). Fall-weaned steers were randomly assigned to graze winter wheat at one of two stocking densities (1.1 steers/ha, HGW and

2.45 steers/ha, LGW) or to graze dormant native range (NR) during the growing phase and subsequent carcass traits were measured. In yr 1 of the study, HCW for HGW was greater ($P < 0.03$) than LGW steers, with NR steers intermediate, but all other carcass measurements did not differ ($P = 0.12$). In yr 2, there were no differences ($P = 0.11$) among treatments in any carcass trait measured (Hersom et al., 2004).

Metabolic differences in adipose tissue depots have been well documented, as well as substrate preferences and utilization within depots. Subcutaneous fat prefers acetate and i.m. fat prefers glucose carbon. Substrate availability may be altered by type of feed or supplement offered. A high roughage feed or supplement should promote greater acetate production, while a high starch feed should promote an increase in propionate production, and thus more glucose. Additionally, it is established that improved forages and small-grains pastures can support adequate gain in growing cattle, and, in the studies reviewed here, with seemingly little effect on carcass traits. These traits may be measured in the live animal with some degree of confidence, to allow for management of similar groups of animals. Therefore, in this study, supplements were formulated to differ in fermentation end products (higher acetate, HR supplement and higher propionate, HS supplement) and stocking rates were adjusted for supplemented and non-supplemented groups so that average BW gain would not differ among treatments. However, we hypothesized cattle receiving the HS supplement would have greater intramuscular fat accretion than HR-supplemented and NC cattle, without concomitant effects on subcutaneous fat accretion. Thus the objectives of this study were to evaluate the effects of supplements differing in glucogenic potential on

subcutaneous and intramuscular fat accretion via ultrasound technology and to utilize these metabolic effects to direct body composition to desired end points.

MATERIALS AND METHODS

Fifty-eight spring-born high grade Bonsmara crossbred steer calves weaned from the commercial cowherd at Texas Agricultural Research and Extension Center-Uvalde were used in this project. Calves were weaned in two groups on September 29 and October 13 of 2004. Calves were vaccinated against viral and bacterial respiratory pathogens (Titanium 5 + P.H.M. Bac-1, AgriLabs, St. Joseph, MO) and clostridial diseases (20/20 Vision 7, Intervet, Millsboro, DE) and were treated with a topical anthelmintic (Cydectin Pour-On, Fort Dodge Animal Health, Fort Dodge, IA) at weaning and re-vaccinated 2 wk later. Steers were backgrounded 60 to 74 d with ad libitum access to bermudagrass hay and fed daily 2.7 kg/hd (AF) of a 65% ground milo, 25% peanut hulls, and 10% cottonseed meal diet with 2.5 mg/kg vitamin premix added. Beginning six days prior to being placed on ryegrass pastures, animals were fed daily an additional 0.90 kg/hd (AF) of a 38% CP cottonseed cake. The allotment of cottonseed cake was increased daily until refusals occurred. The strategy of adding protein to the diet prior to pasture placement was designed to adapt calves to a high nitrogen diet.

At the conclusion of the backgrounding period, steers were weighed and initial ultrasound measurements (ribeye area, REA; percent intramuscular fat, IMF; and 12^{th} rib fat thickness, BF) were obtained by a trained ultrasound technician using a Pie Medical Scanner 200 SCL ultrasound unit (Pie Medical Equipment B.V., The Netherlands) equipped with an 18 cm, 3.5 MHz linear array transducer. Steers were stratified by BW and randomly assigned to one of six management groups. The six management groups were then randomly assigned to one of three treatments. Treatments were 1) no

supplement (NC), which served as the negative control; 2) a commercially available, pelleted high roughage (HR) energy supplement consisting of approximately 10% peanut hulls, 70% soy hulls, and 20% cottonseed hulls at the rate of 1.36 kg/hd (as-fed), hand-fed 6 d/wk; or 3) a corn-based high starch (HS) energy supplement at the same rate and frequency as HR. Cottonseed meal was added to the HS supplement to increase the %CP level to that similar to the HR supplement. Nutritive values of supplements are presented in Table 1.

A 12.7 ha, center pivot irrigated pasture was planted with ryegrass in mid-October, then subdivided into six 2.11 ha paddocks (Figure 2). Treatment groups were randomly assigned to a paddock. Paddocks containing supplemented groups were stocked at 4.74 steers/ha and NC paddocks were stocked at 4.27 steers/ha. Stocking rates were lower in the NC pastures to balance available forage per animal with that of the HS and HR supplemented pastures due to anticipated substitution of forage with supplement. Throughout the trial, pastures were fertilized with a total of 134.6 kg of nitrogen per ha in two applications and irrigated as needed, as determined by experienced technicians at Uvalde. Total forage mass was determined monthly by hand-clipping four randomly placed quadrats (0.25 m) within each paddock and pro-rating to total paddock area; forage allowance was calculated by dividing forage mass of paddock by kg of steers within paddock (Table 2). Forage samples were collected daily by hand-plucking from the upper 7.5 cm of the sward over a ten day period in mid-March to determine nutritive value of forage in each paddock. Forage samples were dried in a forced-air oven, and a composite sample for each paddock was made by taking 1.0 g

Table 1. Chemical composition of high roughage and high starch supplements

Nutrient[a]	**High Roughage (HR)**	**High Starch (HS)**
CP, %	13.8	12.1
ADF, %	44.8	5.7
NDF, %	52.6	10.8
NFC, %	19.9	76.2
TDN, %	64	88
NEm, Mcal/kg	1.43	2.2
NEg, Mcal/kg	0.84	1.52

[a]Values reported on DM basis

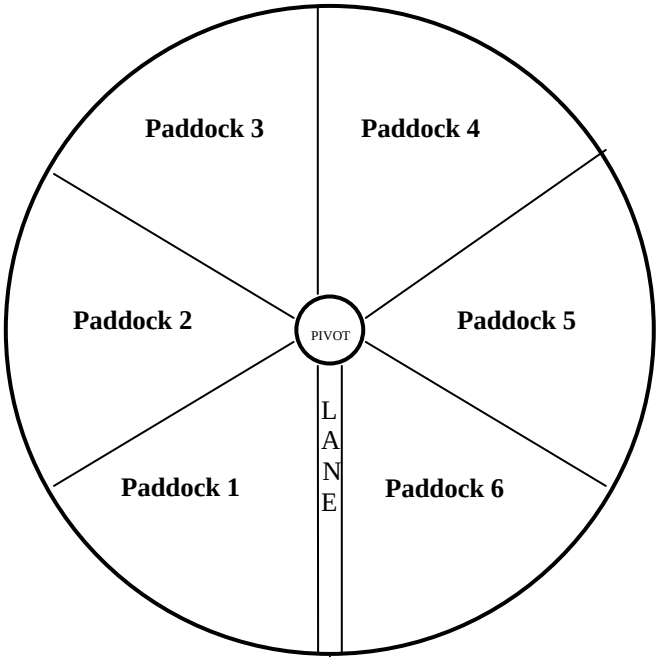


Figure 2. Layout of 2.11 ha paddocks on center-pivot irrigated ryegrass pasture

Table 2. Forage mass and forage allowance of individual ryegrass paddocks

			kg/paddock		kg/kg BW	
Month	**paddock[a]**	**n**	**mean**	**SD**	**mean**	**SD**
Jan						
	1	4	3760	1204	1.37	0.44
	2	4	3543	670	1.29	0.24
	3	4	7495	1707	2.73	0.62
	4	4	3239	1473	1.18	0.54
	5	4	2780	726	1.01	0.26
	6[b]	4	1703	267	0.62	0.10
	6[c]	4	2671	418	0.97	0.15
Feb						
	1	4	3857	2912	1.40	1.06
	2	4	3410	894	1.24	0.33
	3	4	2133	677	0.78	0.25
	4	4	3083	585	1.12	0.21
	5	4	3665	932	1.33	0.34
	6	4	3188	1722	1.16	0.63
Mar						
	1	4	2068	812	0.75	0.30
	2	4	3264	1711	1.19	0.62
	3	4	2519	732	0.92	0.27
	4	4	3570	520	1.30	0.19
	5	4	6001	3202	2.19	1.17
	6	4	3602	1377	1.31	0.50
Apr						
	1	4	4111	1125	1.50	0.41
	2	4	4725	636	1.72	0.23
	3	4	5159	1242	1.88	0.45
	4	4	6143	1652	2.24	0.60
	5	4	6138	2053	2.24	0.75
	6	4	5490	526	2.00	0.19
May						
	1	4	6132	1476	2.23	0.54
	2	4	5560	731	2.04	0.27
	3	4	6081	520	2.21	0.19
	4	4	6596	1824	2.40	0.66
	5	4	4897	428	1.78	0.16
	6	4	5283	970	1.92	0.35

[a]Paddocks 1 and 6 = high roughage supplement; paddocks 2 and 3 = high starch supplement; paddocks 4 and 5 = negative control
[b]Original paddock size of 2.11 ha
[c]Adjusted paddock size of 3.31 ha

from each daily sample. Composite samples were sent to a commercial forage analysis laboratory (Dairy One Forage Laboratory, Ithaca, NY) for chemical analysis (Table 3). Steers were placed on pasture December 17, 2004 and grazed until May 6, 2005 (140 d). On d 28 of the trial, ocular estimates indicated that forage availability in paddock 6 was lower than in remaining paddocks. Paddock 6 was expanded to include an additional 1.2 ha of grazing area during January. Forage standing crop measurements supported this strategy. Forage data in Table 2 for the month of January reflect the enhanced forage availability due to this expansion.

Throughout the grazing period, full BW was measured every 28 d (d 0, 28, 56, 84,112, and 140), and ADG for the grazing period was calculated for each animal. Beginning at 0800, calves from each paddock were gathered and weighed in numerical order according to paddock number. This procedure was followed at each weigh date. A blood sample was collected from each steer on d 28, 56, 84, 112, and 140 via coccygeal venipuncture using a 9.5 ml Vacutainer blood tube (Preanalytical Solutions, Franklin Lakes, NJ). Blood samples were placed on ice until all samples were collected; samples were centrifuged and serum was placed in a plastic vial and frozen. Additionally, ultrasound measurements were obtained on d 56 and 112, using the same equipment and technician as was used for the initial scan, to evaluate changes in REA, IMF, and BF. Although results are not presented, a procedure to determine individual forage intake was conducted. On d 74 of the study, cattle were administered an alkane controlled-release bolus (Captec; NuFarm Ltd., Auckland, New Zealand). Beginning on d 84 and continuing daily through d 94, fresh fecal samples from each steer were

Table 3. Chemical composition of irrigated ryegrass paddocks sampled in March

Item[a,b]	**NC**[c]	**HR**[d]	**HS**[e]	**SEM**	***P***
CP, %	27.9	27.4	27.7	0.61	0.85
ADF, %	20.2	20.6	19.6	0.39	0.30
NDF, %	37.7	37.6	40.3	1.50	0.45
NFC, %	28.1	28.5	26.0	0.94	0.27
TDN, %	71.5	71.5	71.0	0.71	0.85
NEm, Mcal/kg	0.77	0.77	0.75	0.007	0.35
NEg, Mcal/kg	0.49	0.49	0.47	0.007	0.35

[a]Values reported on dry matter basis

[b]Nutrient content based on lab analysis performed by Dairy One Forage Laboratory, Inc., Ithaca, NY

[c]Negative control treatment

[d]High roughage supplement

[e]High starch supplement

collected. Cattle were observed in their respective paddocks. Upon defecation, steer was identified and a fresh fecal sample was collected, avoiding forage and soil contamination, into a re-sealable plastic bag. Steer ear-tag number, date, and paddock number was recorded on the bag. Daily, after samples from all steers were collected, bags were flattened, sealed, and placed in a freezer. In conjunction with the forage intake procedure, a method was used to determine individual supplement intake (data not presented). On d 85 through d 90 of the trial, 15.5 g of titanium dioxide was mixed with 0.45 kg of supplement, which was then added to the daily allotment of supplement (13.6 kg/paddock) in the bunk. After thorough mixing in the bunk, approximately 0.45 kg was removed by random sampling and placed in re-sealable plastic bags for storage until analysis is conducted.

At the conclusion of grazing, cattle were transported to the feedlot at West Texas A&M University's Nance Ranch in Canyon, TX. Steers remained in treatment groups and were fed a typical finishing diet (Table 4). Steers were weighed upon arrival, then again 3 d later, which served as initial feedlot weight. Steers were then weighed every 28 d, ADG was calculated for each 28 d period and overall (119 d), and pen feed intake (DM) was recorded every 28 d for the duration of finishing. Additionally, ultrasound measurements were obtained twice during the finishing phase (d 182 and d 231 of the experiment). On d 231 of the experiment, foot scores were assigned to each steer. Foot scores were based on a scale of 1 to 5, with 1 being sound and 5 being unsound. Steers were on feed 119 d.

Table 4. Ingredient composition of finishing diet and supplement

Item	% of DM
Finishing Diet	
Steam-flaked corn	73.0
Alfalfa hay, ground	12.5
Cottonseed meal, 41%	4.0
Steep:molasses (70:30)[a]	4.0
Supplement[b]	3.5
Yellow grease[c]	3.0
Finishing Supplement	
Corn grain, ground	22.49
Limestone	33.67
Potassium chloride	8.57
Magnesium oxide	2.54
Ammonium sulfate	5.95
Salt	7.14
Urea	17.14
Mineral oil, white	1.00
Cobalt carbonate	0.0012
Copper sulfate	0.112
Iron sulfate	0.196
EDDI	0.0018
Manganese oxide	0.148
Selenium premix, 0.2%	0.429
Zinc sulfate	0.332
Vitamin A, 30,000 IU/g	0.197
Vitamin E, 500 IU/g	0.077

[a] Contained 0.4% (w/w) propionic acid to inhibit mold growth

[b] Dry, meal-form supplement

[c] Rendox AET (Kemin Americas, Des Moines, IA) was added at 0.1% (w/w) to prevent oxidation

Cattle were harvested at a federally inspected commercial facility (Tyson, Amarillo, TX) and carcass information (dressing percentage, DP; hot carcass weight, HCW; ribeye area, REA; marbling score, MARB; fat thickness, FAT; yield grade, YG; quality grade, QG; and shear force, SHEAR) was collected by an independent carcass data collection service (Cattlemen's Carcass Data Service, Canyon, TX).

Forage and supplement consumption of individual steers was estimated using Level 1 of the computer model of the Beef Cattle NRC (National Research Council, 1996). Average BW and ADG was calculated for each paddock and used in the model to first establish an estimate of forage intake, with supplement consumption fixed at target daily consumption (0 kg, 1.20 kg and 1.19 kg, DM basis; NC-, HR-, and HS-supplement, respectively). Once forage intake was estimated for each paddock, that value was fixed in the model, and for HR- and HS-fed steers, supplement consumption was manipulated until ADG predicted

in the model was equivalent to actual ADG of each individual. To estimate forage intake of NC-fed steers, forage intake in the model was manipulated so that predicted ADG and actual ADG were equal. Assumptions about environmental and animal conditions in the model were based on available weather data and knowledge about the cattle, and were constant across treatments.

Repeated measures analysis of performance and ultrasound data was performed using mixed model (PROC MIXED) procedures of SAS v.8 (SAS Inst. Inc., Cary, NC). Fixed effects in the model included treatment, day, and treatment X day interaction. Day served as repeated effect and subject effect was described as steer within treatment. The

autoregressive covariance structure was used with a lag of one. Carcass traits (i.e., endpoint measurements; DP, HCW, REA, MARB, FAT, and SHEAR) were analyzed as a completely randomized design, one-way treatment structure, using the general linear model (PROC GLM) procedures of SAS with steer as experimental unit and treatment as main effect. A chi-square test for equal proportions was used in the frequency procedures (PROC FREQ) of SAS to evaluate quality grade distribution.

Least squares procedures (PROC GLM) of SAS were used to examine effect of treatment on gain/ha and treatment effect on forage allowance (kg/steer). In both models, pasture served as the experimental unit and treatment served as a fixed effect. Correlation coefficients among traits were determined using the correlation procedures (PROC CORR) of SAS.

RESULTS AND DISCUSSION

Forage and supplement intake were estimated for each individual steer using the computer model of the Beef Cattle NRC (NRC, 1996) (Table 5). Mean modeled intake was 13% greater than observed intake for HR-fed steers, but matched observed intake in HS-fed steers. The standard deviation in modeled intake reflects the variability in steer ADG and may be a contribution to low sensitivity in statistical comparisons. However, the use of mixed model procedures allows the random variability associated with subject (steer) to be modeled, and should account for the apparent variability in supplement intake.

All BW and ultrasound responses analyzed as repeated measures increased over time ($P < 0.01$).

Performance of Steers During the Growing Phase

There were no differences ($P = 0.71$) in BW due to treatment effects during the growing phase (Table 6). A treatment by time interaction ($P = 0.05$) for BW was due to a treatment rank change; however, this rank change occurred on d 231 during the finishing phase. This lack of BW response to treatment is consistent with experimental objectives and was expected due to the adjustment of stocking rates in NC paddocks to account for substitution of forage with supplement, and indicates that energy consumption from forage and supplements was similar among all treatments.

Forage quality was similar ($P > 0.27$, Table 3) among treatment groups. Gain per ha was numerically greater ($P = 0.22$) in HS and HR supplemented paddocks than in NC

Table 5. Supplement intake of high grade Bonsmara steers grazing ryegrass pasture and supplemented with high roughage (HR) or high starch (HS) energy supplements

Item[a]	**HR**	**HS**
Actual Intake, kg	1.20	1.19
Predicted Intake, kg	1.36	1.19
Min., kg	0.00	0.69
Max., kg	3.03	1.62
St. dev.	0.98	0.33

[a]Values reported on DM basis

Table 6. Least squares means for BW(kg) of high grade Bonsmara steers grazing ryegrass pasture with no supplement (NC) or supplemented with high roughage (HR) or high starch (HS) energy supplements[a]

Item[b]	NC	HR	HS	SEM
d -15	250.3	248.9	251.0	8.39
d 56	298.4	297.6	303.6	8.39
d 112	362.4	357.9	363.4	8.39
d 182	432.3	423.5	438.5	8.39
d 231	521.7	503.5	516.3	8.39
Overall	373.0	366.3	374.6	7.92

[a]Treatment x time interaction effect, $P = 0.05$; treatment effect, $P = 0.71$

[b]d -15 = backgrounding phase prior to growing phase; d 56 and d 112 = growing phase; d 182 and d 231 = finishing phase

paddocks due to stocking rate (637.7, 628.2, and 571.5 kg ± 22; HS, HR, and NC paddocks, respectively). Furthermore, forage allowance, expressed as kg/steer, was similar ($P > 0.24$) among treatments for all months except April, in which there was a tendency ($P = 0.07$) for forage allowance to be greater in NC paddocks than the HS and HR supplemented paddocks (Table 7), and was adequate enough to support maximum animal growth. Redmon et al. (1995) reported that forage allowance should be greater than 20% of BW to support maximal growth. Because forage quality, forage allowance, and BW were similar for all treatments, any observed treatment effects on other responses must be due to something other than total energy consumption (i.e., not the amount of energy, but rather type of energy consumed).

Due to lack of treatment influences on BW, no differences ($P = 0.96$) were observed for ADG among treatments. Gain for NC-fed steers grazing irrigated ryegrass was 0.96 kg/d (Table 8). This is similar to daily gains reported by Grigsby et al. (1991) in which non-supplemented steers and heifers grazing rye-ryegrass pastures at a similar stocking rate (4.13 steers/ha) gained 0.99 kg and 1.07 kg (yr 1 and yr 2, respectively) as well as gains for steers grazing irrigated winter wheat pastures (1.03 kg/d; Choat et al., 2003). On the other hand, gains in the current study were greater than ADG of steers grazing ryegrass pastures (0.70 kg/d) as reported by Lippke and Holloway (1995) and cattle grazing rye and ryegrass pastures (0.72 kg/d; Aiken et al., 2004), however, stocking rates, forage quality, and forage allowance were not reported in those studies, and could have contributed to lower gains.

Table 7. Least squares means for forage allowance (kg/steer) for high grade Bonsmara steers grazing ryegrass pasture with no supplement (NC) or supplemented with high roughage (HR) or high starch (HS) energy supplements

Item	**NC**	**HR**	**HS**	**SEM**	***P***
Jan	334	273	552	129.5	0.40
Feb	375	352	277	45.6	0.40
Mar	532	283	289	92.2	0.24
Apr	682[a]	480[b]	494[b]	41.7	0.07
May	639	571	584	61.3	0.73

[a,b]Means in the same row without a common superscript tend to differ ($P < 0.1$)

Table 8. Least squares means for ADG in growing and finishing phases for high grade Bonsmara steers grazing ryegrass pasture with no supplement (NC) or supplemented with high roughage (HR) or high starch (HS) energy supplements

Item	**NC**	**HR**	**HS**	**SEM**	*P*
Growing ADG,kg	0.96	0.95	0.96	0.04	0.96
Feedlot ADG, kg	1.50	1.36	1.39	0.07	0.46

Gains for HR- and HS-fed steers were 0.95 kg/d and 0.96 kg/d, respectively (Table 8). Horn et al. (1995) supplemented steers grazing winter wheat and achieved gains of 1.07 kg/d, which were similar to those in the current study, however, stocking density was much lower (1.65 steers/ha) in that study, as compared to 4.74 steers/ha in the current study. Crossbred steers grazing ryegrass pastures and consuming 0.90 kg/d of a monensin-containing corn-based supplement gained 1.16 kg/d at a stocking density of 3.7 steers/ha (Hubbell et al., 2000). In the study by Hubbell et al. (2000), shorter grazing duration (102 d) during months when forage mass and quality might have been higher and the use of growth-promoting implants may have contributed to greater gains than those observed in the current study.

Performance of Steers During the Finishing Phase

There were no differences ($P = 0.71$) in BW during the finishing phase due to treatment during the growing phase (Table 6). This response is consistent with the fact that ADG and BW were similar among treatments at feedlot entry and cattle were consuming the same ration with the same amount of energy in the finishing phase. In agreement with the current study, Horn et al. (1995) reported no difference ($P = 0.55$) in final feedlot BW of steers that were non-supplemented or supplemented while grazing winter wheat pasture during the growing phase.

Due to lack of treatment influences on BW, no differences ($P = 0.46$) were observed for ADG among treatments. Gains during finishing were 1.50, 1.36, and 1.39 kg/d (± 0.07) for NC-, HR-, and HS-fed steers, respectively (Table 8). Horn et al. (1995) reported gains during finishing of 1.72 kg/d vs. 1.63 kg/d (yr 2; $P < 0.05$) and 1.52 kg/d

vs. 1.51 kg/d (yr 3; $P = 0.80$) for steers that were non-supplemented vs. supplemented during the growing phase while grazing winter wheat pasture. The lack of differences in BW and ADG among treatments is consistent with experimental objectives, which were to alter i.m. fat accretion without concomitant effects on BW.

Effects on Carcass Traits Measured via Ultrasound

Ultrasound technology was utilized in this experiment to evaluate carcass traits, and, more specifically, effects of energy supplementation on s.c. and i.m. adipose tissue accretion in steers during the growing phase and potential carryover effects during the finishing phase.

There was no treatment by time interaction ($P = 0.47$) for ultrasound REA responses (Table 9). Treatment influenced ultrasound REA ($P = 0.05$); HS-fed steers had larger ultrasound REA than HR-fed steers; NC steers were intermediate. Apparent effects on REA may be explained by the reported relationship between BW and REA (Hamlin et al., 1995). These authors found ultrasound estimates of REA increased ($P < 0.001$) in a quadratic manner as BW increased; BW accounted for 72% of the variation in REA (Hamlin et al., 1995). In the current study, although not significant, BW was numerically greater for HS-fed and NC steers than that of HR-fed steers and is consistent with REA responses. Additional explanation for this response may be due to exposure to a greater amount of starch in the diet earlier in growth. Early weaned heifers that were limit-fed a 90% concentrate diet for 119 d prior to entering the feedlot had larger ($P < 0.01$) carcass longissimus muscle area, expressed as cm^2 per 100 kg of carcass

Table 9. Least squares means for ultrasound REA (cm^2) of high grade Bonsmara steers grazing ryegrass pasture with no supplement (NC) or supplemented with high roughage (HR) or high starch (HS) energy supplements[a]

Item[b]	NC	HR	HS	SEM
d -15	42.7	42.4	43.8	1.19
d 56	44.4	45.1	45.8	1.19
d 112	52.5	51.3	55.5	1.19
d 182	61.4	59.4	61.6	1.19
d 231	73.7	70.2	73.8	1.19
Overall	54.9	53.7	56.1	0.73

[a]Treatment x time interaction effect, $P = 0.47$; treatment effect, $P = 0.05$

[b]d -15 = backgrounding phase prior to growing phase; d 56 and d 112 = growing phase; d 182 and d 231 = finishing phase

weight, than early-weaned heifers that grazed endophyte-infected tall fescue for 18 mo before entering the feedlot (Wertz et al., 2001). In the current study, steers only received a supplement, not full feed during the growing period, which may have reduced the magnitude of separation. However, results of the current study are directionally consistent with responses reported by Wertz et al. (2001). Alternatively, inherent variability in ultrasound measurements may have created an anomalous separation. Herring et al. (1994) reported correlations for repeatability of ultrasound REA measures that ranged from 0.36 to 0.90.

Treatment by time interaction effects ($P = 0.02$) on BF resulted from rank changes of treatments among days (Table 10). On d 112 (during the growing phase), steers HS-fed steers had greater BF than those NC steers, with steers HR-fed steers intermediate. On d 182 (during the finishing phase), steers previously fed HS had greater BF than HR treated steers and NC treated steers were intermediate. On d 231, steers previously fed NC had greater BF than those fed HS or HR. This effect may be attributed to the relationship of fat thickness and BW. Hamlin et al. (1995) analyzed growth curves to determine relative changes in ultrasound measures of BF over time and reported BW had a quadratic ($P < 0.001$) effect, accounting for 46% of variation. In the current study, moderate correlations among BW and BF ($P < 0.04$) for d 56, d 112, d 182, and d 231 were observed (Table 11). In HS-fed steers, greater BF is related to greater numerical BW in those steers. Inconsistent with that relationship are the

Table 10. Least squares means for ultrasound BF (cm) of high grade Bonsmara steers grazing ryegrass pasture with no supplement (NC) or supplemented with high roughage (HR) or high starch (HS) energy supplements[a]

Item[b]	NC	HR	HS	SEM
d -15	0.41	0.37	0.36	0.025
d 56	0.39	0.41	0.39	0.025
d 112	0.45[x]	0.50[xy]	0.51[y]	0.025
d 182	0.66[xy]	0.64[x]	0.71[y]	0.025
d 231	0.96[x]	0.89[y]	0.90[y]	0.025
Overall	0.57	0.56	0.57	0.016

[a]Treatment x time interaction effect, $P = 0.02$; treatment effect, $P = 0.81$

[b]d -15 = backgrounding phase prior to growing phase; d 56 and d 112 = growing phase; d 182 and d 231 = finishing phase

[x,y]Means in the same row without a common superscript differ, $P \leq 0.05$

Table 11. Correlations (*P*-values) among BW and ultrasound measures of BF

Item[a]	BF 56	BF 112	BF 182	BF 231
BW 56	0.419	0.486	0.422	0.318
	(0.001)	(0.0001)	(0.001)	(0.015)
BW 112	0.388	0.514	0.438	0.269
	(0.003)	(<0.0001)	(0.0006)	(0.041)
BW 182	0.366	0.431	0.443	0.302
	(0.0047)	(0.0007)	(0.0005)	(0.021)
BW 231	0.339	0.361	0.292	0.291
	(0.009)	(0.005)	(0.0261)	(0.027)

[a]BW = body weight; BF = ultrasound fat thickness; d 56 and d 112 = growing phase; d 182 and d 231 = finishing phase

observed responses of HR-fed steers. The HR-fed steers had greater BF at a lower numerical BW; this may due to greater amounts of acetate provided by the HR supplement, which is the preferred substrate for s.c. fat (Hood and Allen, 1978; Smith and Crouse, 1984).

Neither treatment nor the interaction of time and treatment affected IMF ($P > 0.20$; Table 12). It is possible that the supplements and forage did not differ greatly enough in their fermentation profiles to differ in the supply of preferred substrates for s.c. and i.m. fat depots as to elicit a response great enough to be detected and separated. High roughage diets promote greater acetate production, whereas high starch diets promote increased propionate production (Owens and Goetsch, 1988). Because forage made up such a high percentage of the total diet, the amount of fermentation products from a small package supplement may not have been enough to overcome the amounts produced by the forage.

As previously discussed, ultrasound measures of REA differed among treatments; however IMF was not affected by treatment. These observations suggest treatment effects on REA with no difference in IMF support our hypothesis that HS-fed steers accreted a greater amount (mass) of i.m. fat, despite a greater increase in REA, without concomitant effects on BF or BW. Because IMF is a proportion (i.e., relative to REA), constant IMF with increasing REA can only occur if the mass of i.m. fat is also increasing. On the contrary, ultrasound measurements are imperfect and the possibility exists for under- or over-estimation of traits. In the current study, if ultrasound measures for REA were artificially inflated, IMF would be artificially deflated because it is

Table 12. Least squares means for ultrasound IMF (%) of high grade Bonsmara steers grazing ryegrass pasture with no supplement (NC) or supplemented with high roughage (HR) or high starch (HS) energy supplements[a]

Item[b]	NC	HR	HS	SEM
d -15	2.65	2.60	2.59	0.090
d 56	2.68	2.58	2.65	0.090
d 112	2.55	2.55	2.58	0.090
d 182	2.71	2.96	2.93	0.090
d 231	3.32	3.12	3.17	0.090
Overall	2.78	2.77	2.78	0.053

[a] Treatment x time interaction effect, $P = 0.20$; treatment effect, $P = 0.98$

[b] d -15 = backgrounding phase prior to growing phase; d 56 and d 112 = growing phase; d 182 and d 231 = finishing phase

calculated using REA as a variable in the equation. If REA were corrected, IMF would actually increase, again supporting the hypothesis that energy supplements differing in glucogenic potential alter i.m. fat accretion.

Carcass Traits

Dressing percentages were similar among treatments ($P = 0.19$; Table 13) and are similar to expected dressing percentage of beef (62%) as reported by Kauffman and Breidenstein (1994) and current industry dressing percentage (63.31%) as reported by USDA (2005). There were no differences among treatments for HCW ($P = 0.48$), carcass REA ($P = 0.85$), or FAT ($P = 0.60$) (Table 13). By design, BW among treatments did not differ throughout the growing or finishing phases; as a result HCW was similar among treatments. A lack of difference in carcass REA among treatments is likely due to the similarity in HCW among treatments. Other researchers have demonstrated that REA increases linearly with increasing HCW (May et al., 1992; Bruns et al., 2004). However, this is inconsistent with the ultrasound REA response in which a difference in ultrasound REA among treatments was detected. This is probably due to a combination of error in both ultrasound measurements and carcass measurements; correlation coefficients revealed no significant relationship between ultrasound REA scans prior to and during the growing phase to carcass REA ($P > 0.16$; Tables 14, 15, and 16). Ultrasound scans taken during the finishing phase had low to moderate correlations with carcass REA (d 182, r = 0.45, $P = 0.004$; d 231, r = 0.30, $P = 0.02$; Tables 17 and 18). Greiner et al. (2003) reported the correlation between ultrasound (within 5 d of harvest) and carcass REA was 0.86. Wall et al. (2004) scanned cattle at

Table 13. Least squares means for carcass traits of high grade Bonsmara steers previously grazing ryegrass pasture with no supplement (NC) or supplemented with high roughage (HR) or high starch (HS) energy supplements prior to feedlot entry

Item[a]	**NC**	**HR**	**HS**	**SEM**	*P*
DP, %	62.99	62.98	63.74	0.35	0.19
HCW, kg	341.24	329.77	338.18	7.09	0.48
REA, cm^2	85.74	84.32	85.16	1.79	0.85
FAT, cm	1.21	1.09	1.22	0.10	0.60
MARB	363.9^{x}	400.5^{y}	416^{y}	19.3	0.15
SHEAR, kg	3.19	2.80	2.64	0.12	0.004

[a]DP = dressing percentage, HCW = hot carcass weight, REA = ribeye area, FAT = fat thickness, MARB = marbling number (300 = slight^{00}, 400 = small^{00}), and SHEAR = shear force

[x,y]Means in the same row without a common superscript tend to differ ($P = 0.15$)

Table 14. Correlations (*P*-values) among ultrasound and carcass measurements for steers on d -15

	Carcass Traits[a]		
Item	REA	FAT	MARB
Ultrasound Traits[b]			
REA	0.05	0.32	-0.06
	(0.71)	(0.02)	(0.66)
BF	-0.06	0.34	-0.06
	(0.65)	(0.0098)	(0.66)
IMF	0.11	-0.013	-0.001
	(0.39)	(0.92)	(0.99)

[a]Carcass traits: REA = carcass ribeye area; FAT = carcass fat thickness; MARB = carcass marbling score

[b]Ultrasound traits: REA = ultrasound ribeye area; BF = ultrasound fat thickness; IMF = ultrasound percent intramuscular fat

Table 15. Correlations (*P*-values) among ultrasound and carcass measurements for steers on d 56

	Carcass Traits[a]		
Item	REA	FAT	MARB
Ultrasound Traits[b]			
REA	0.18	0.25	-0.02
	(0.18)	(0.06)	(0.89)
BF	-0.14	0.32	0.14
	(0.30)	(0.01)	(0.31)
IMF	-0.13	-0.06	0.14
	(0.33)	(0.65)	(0.29)

[a]Carcass traits: REA = carcass ribeye area; FAT = carcass fat thickness; MARB = carcass marbling score

[b]Ultrasound traits: REA = ultrasound ribeye area; BF = ultrasound fat thickness; IMF = ultrasound percent intramuscular fat

Table 16. Correlations (*P*-values) among ultrasound and carcass measurements for steers on d 112

	Carcass Traits[a]		
Item	REA	FAT	MARB
Ultrasound Traits[b]			
REA	0.12	0.30	0.105
	(0.16)	(0.02)	(0.43)
BF	-0.13	0.45	0.25
	(0.34)	(0.0004)	(0.06)
IMF	0.14	0.25	0.32
	(0.31)	(0.06)	(0.015)

[a]Carcass traits: REA = carcass ribeye area; FAT = carcass fat thickness; MARB = carcass marbling score

[b]Ultrasound traits: REA = ultrasound ribeye area; BF = ultrasound fat thickness; IMF = ultrasound percent intramuscular fat

Table 17. Correlations (*P*-values) among ultrasound and carcass measurements for steers on d 182

	Carcass Traits[a]		
Item	REA	FAT	MARB
Ultrasound Traits[b]			
REA	0.45	0.20	-0.012
	(0.0004)	(0.12)	(0.93)
BF	-0.03	0.41	-0.075
	(0.82)	(0.0013)	(0.56)
IMF	0.13	0.32	0.52
	(0.34)	(0.016)	(<0.0001)

[a]Carcass traits: REA = carcass ribeye area; FAT = carcass fat thickness; MARB = carcass marbling score

[b]Ultrasound traits: REA = ultrasound ribeye area; BF = ultrasound fat thickness; IMF = ultrasound percent intramuscular fat

Table 18. Correlations (*P*-values) among ultrasound and carcass measurements for steers on d 231

	Carcass Traits[a]		
Item	REA	FAT	MARB
Ultrasound Traits[b]			
REA	0.31	0.29	-0.11
	(0.02)	(0.03)	(0.42)
BF	-0.04	0.593	-0.07
	(0.76)	(<0.0001)	(0.60)
IMF	0.004	0.305	0.232
	(0.98)	(0.02)	(0.08)

[a]Carcass traits: REA = carcass ribeye area; FAT = carcass fat thickness; MARB = carcass marbling score

[b]Ultrasound traits: REA = ultrasound ribeye area; BF = ultrasound fat thickness; IMF = ultrasound percent intramuscular fat

regular intervals to determine if ultrasound measures could be used to predict carcass composition prior to harvest. Correlation coefficients for ultrasound REA and carcass REA were 0.52 (100 d prior to harvest) and 0.66 (7 d prior to harvest). It appears that scans taken closer to harvest are more strongly correlated to carcass REA; in the current study, the last scan obtained was 31 d prior to harvest, which may explain the lower correlation.

Treatment did not influence carcass fat thickness ($P = 0.60$; Table 13). The response in FAT to treatments is consistent with ultrasound BF response on d 231. Other studies have reported linear (May et al., 1992), exponential (Brethour, 2000b), or quadratic (Bruns et al., 2004) increases in s.c. fat thickness as HCW increased. Due to this relationship, and because HCW in the current study did not differ, the lack of differences in FAT is not unexpected. We hypothesized that supplementation would affect i.m. fat accretion without concomitant effects on s.c. fat or BW. Moderate correlations were detected between ultrasound measures of BF and carcass FAT (d -15, r = 0.34, $P = 0.01$; d 56, r = 0.32, $P = 0.01$; d 112, r = 0.45, $P = 0.004$; d 182, r = 0.41, $P = 0.001$; and d 231, r = 0.59, $P < 0.0001$; Tables 14, 15, 16, 17, and 18). Other studies have reported moderate to high correlations, with the strongest correlation occurring within 5 to 7 d pre-harvest (r = 0.89, Greiner et al., 2003; r = 0.74, Wall et al., 2004).

There was a tendency ($P = 0.15$) for MARB to be greater for HS-fed steers than NC-fed steers with HR-fed steers intermediate (Table 13). The tendency for carcass MARB to be higher in HS-fed steers with no difference in carcass REA agrees with the response seen in ultrasound measures of REA and IMF, in which treatment affected

REA, without affecting IMF. This may be interpreted that the HS-fed cattle were indeed accreting more IMF along with increasing REA. If REA is greater, and IMF is constant, the HS-fed steers must have more total i.m. fat (mass). Conversely, in previous discussion, the possibility that ultrasound REA measures were artificially inflated and IMF was deflated was addressed. If this indeed occurred and was corrected, IMF would actually increase in the HS-fed cattle. When evaluating carcass measurements in the current study, there were no differences in REA among treatments; however there was a tendency for MARB to be greater for supplemented steers than non-supplemented steers, with HS-fed steers having larger numerical MARB than HR-fed steers. This tendency also appears to agree with our hypothesis that energy supplements differing in glucogenic potential fed during the growing phase may partition nutrients in such a way to favor i.m. fat accretion. Therefore, these carcass responses are consistent with ultrasound measures when considered cumulatively. It is possible that the amount of supplement offered was too small to elicit a response great enough to be statistically separated. Ultrasound IMF on different days was low to moderately correlated to carcass MARB (d 112, r = 0.32, $P = 0.02$; and d 182, r = 0.52, $P < 0.0001$; Tables 14, 15, 16, 17, and 18). In a study by Brethour (2000a), 144 calves were ultrasounded a few days after weaning, and an estimate of marbling score was determined using an image analysis procedure. The correlation between estimated post-weaning marbling score and carcass marbling score was 0.32.

Treatment affected SHEAR ($P = 0.004$, Table 13). Supplemented steers had lower shear force values (2.64 kg and 2.80 kg, HS and HR-fed steers, respectively) than

non-supplemented steers (3.19 kg) and values for HS-fed steers were numerically lower than those for HR-fed steers. Several studies have evaluated Warner-Bratzler shear force. Miller et al. (2001) classified steaks with a shear force value < 3.0 kg as tender, whereas Belew et al. (2003) classified muscles as very tender with a shear force of < 3.2 kg. Huffman et al. (1996) reported that steaks with a shear force value of 4.1 kg or less were needed to ensure a 98% consumer acceptability level, both in the home and restaurant. Additionally, the response in SHEAR in the current study is consistent with the tendency for MARB to be greater in supplemented steers than in the non-supplemented steers.

Treatment did not affect ($P = 0.27$) the proportion of steers that graded choice or select (Table 19). However, the numerical differences in the proportion of steers among treatments that graded choice or select is notable. Within the NC treatment, 38.9% graded choice, while 61.1% graded select. Steers supplemented with HR graded 50% choice and 50% select. High starch (HS) supplemented steers were 65% choice and 35% select. This is directionally consistent with our hypothesis that i.m. fat would be increased in HS-fed steers. The lack of statistical difference is likely due to a lack of sensitivity in the chi-square test because of the small number of animals per treatment.

Body weight and ADG did not differ among treatments throughout growing and finishing phases; this is consistent with experimental objectives due to relationships of BW with body composition traits. Ultrasound REA was greater for HS-fed steers than HR-fed steers, with NC steers intermediate and no differences in IMF were observed among treatments. This suggests HS-fed cattle were increasing i.m. fat (mass), despite a

Table 19. Quality grade distribution of high grade Bonsmara steers previously grazing ryegrass pasture with no supplement (NC) or supplemented with high roughage (HR) or high starch (HS) energy supplements prior to feedlot entry

Item[a]	**NC**	**HR**	**HS**
USDA Choice, %	38.9	50	65
USDA Select, %	61.1	50	35

[a]$P = 0.27$

greater increase in REA. However, ultrasound measurements are imperfect and the possibility exists for under- or over-estimation of traits; if ultrasound measures for REA were artificially inflated, IMF would be artificially deflated because it is calculated using REA as a variable in the equation. If REA were corrected, IMF would actually increase, again supporting the hypothesis that energy supplements differing in glucogenic potential alter i.m. fat accretion. Carcass measures of fat thickness were similar among treatments, which supports our objectives. There were no differences in carcass REA among treatments; however there was a tendency for MARB to be greater for supplemented steers than non-supplemented steers; MARB for HS-fed cattle was numerically greater than that of HR-fed steers. This tendency also appears to agree with our hypothesis that energy supplements differing in glucogenic potential fed during the growing phase may partition nutrients in such a way to favor i.m. fat accretion. Additionally, quality grade distribution was more favorable for HS-fed steers than HR- and NC-fed steers. It is possible that the amount of supplement offered was too small to elicit a response great enough to be statistically separated.

SUMMARY

Performance, ultrasound, and carcass traits were evaluated on fifty-eight steers to determine the effects of energy supplementation during the growing phase on s.c. and i.m. fat accretion during growing and finishing phases and subsequent carcass characteristics. Supplements were designed to differ in fermentation end products, thus providing preferred substrates for s.c. and i.m. fat depots, while still containing approximately the same amount of energy so that growth performance would not be affected.

Treatment during the growing phase had no effect on BW or ADG of steers during the growing and finishing phases, consistent with experimental objectives. Additionally, treatment had no effect on ultrasound measures of IMF, but influenced ultrasound REA. Ultrasound REA was greater for HS-fed steers than HR-fed steers, with NC steers intermediate. Differences in REA among treatments with similar IMF suggest that HS-fed steers accreted a greater total amount of i.m. fat.

Treatments did not affect HCW, carcass REA, or FAT, but tended to affect MARB. Supplemented steers tended to have greater MARB than non-supplemented steers, and MARB for HS-fed cattle was numerically greater than that of HR-fed steers. The relationship between carcass REA and MARB is consistent with the relationship observed between ultrasound REA and IMF. These observations suggest that source of energy supplementation partitioned nutrients during the growing phase to favor i.m. fat accretion.

It is possible that the magnitude of changes among treatments were too subtle to be statistically separated due to variability in the response. Further investigation of energy supplementation effects on s.c. and i.m. fat deposition is required to define clear responses. Increasing the amount of supplement offered may elicit a greater response.

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